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VISUAL TEMPORAL FILTERING AND INTERMITTENT VISUAL
DISPLAYS(U) ROCKEFELLER UNIV NEW YORK R SHAPLEY
08 AUG 86 AFOSR-TR-86-2026 AFOSR-84-0278

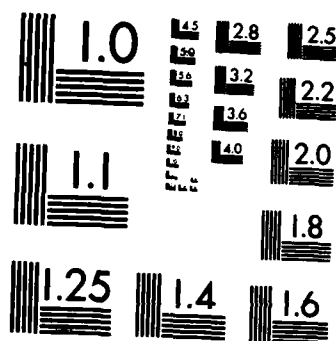
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Final Progress Report for AFOSR grant 84-0278

Period: 1 September 1984 to July 1, 1986

Professional personnel

Robert Shapley, Associate Professor, 20% time and support
 Ehud Kaplan, Associate Professor, 20% time and effort
 Michelangelo Rossetto, Research Associate, 20% time and support
 Margo Greene, Research Assistant, 12% time and effort

Summary of ProgressIntermittent Displays and Contrast Sensitivity.

The initial objective of this project was to investigate the relation between the temporal filtering properties of visual neurons and the performance of human observers when they view intermittent visual displays, e.g. video screens. The scope of the project was reduced by the support level set by AFOSR to focus just on human observers and to omit any experiments on neurons in experimental animals. Specific aims of the project initially included the design and fabrication of a variable-raster-rate electro-optic display, and the use of this novel device to measure the contrast sensitivity function at different raster rates. These two specific aims have been reached and are described as follows.

The variable raster rate display was designed and built by Michelangelo Rossetto and Norman Milkman, Research Associates in the Biophysics Laboratory. The instrument makes use of a digital counter and multiplying (or dividing) D/A converter to produce a raster at variable rates under digital computer control. In this device, as in previous electronic visual displays designed by Messrs. Rossetto and Milkman, the raster sweep is made by integrating a constant current which is the output of a D/A converter. In this case the current comes from a dividing Model 7520 D/A converter where the current is divided by a number from the computer which is exactly proportional to the sweep duration. The sweep duration is controlled by another number from the computer which is fed to a digital counter which divides the crystal clock rate of the instrument by a constant, thus increasing the sweep time and thereby lowering the raster rate by a constant amount.

The contrast sensitivity function was measured with raster rates of 270 Hz, 60 Hz, and 30 Hz. There was little effect of raster rate on contrast sensitivity, as shown in Figure 1. I also made preliminary measurements of displacement sensitivity, a known hyperacuity, with rasters of the same rates, and also found very little difference in displacement detection. Although it is part of the research plan to measure contrast sensitivity after long-term viewing of a video screen, I have not yet done these experiments because of the disappointingly small effects of simultaneous masking by rasters. Instead I have redirected my research on

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this project into the study of the neural basis of hyperacuity and contrast sensitivity, and the mechanisms of seeing "subjective" or interpolated contours, like those in the Kanizsa triangle.

Neural Basis of Hyperacuity.

Following a suggestion made by Dr. J.G. Robson of the University of Cambridge, my colleague Dr. Jonathan Victor and I studied the spatial localization acuity of retinal ganglion cells in the cat. Some of our initial results are reported in Shapley and Victor (1986). We found that retinal ganglion cells can respond to spatial displacements more than ten times smaller than the radius of the receptive field center. This neural hyperacuity is a consequence of the low noise and high gain of the retina. The retinal signal is the contrast of the stimulus times the contrast gain, while the noise is estimated from the variability in the impulse firing rate. We found empirically that the maximal signal/noise ratio for the ganglion cells we studied was about 20, so we took a conservative estimate of about 15 for the signal/noise. In all of our equations we have referred to the signal/noise ratio as the parameter, Z . It is straightforward to show that the spatial frequency resolution, of a linear receptive field with a spatial frequency response $G(k)$, is:

$$k_{\text{resol}} = G_{\text{inv}}(1/Z)$$

The threshold for displacement, Δx_D , is equal to:

$$\Delta x_D = \frac{1}{2\pi Z k_D G(k_D)}$$

where k_D is the spatial frequency that gives the optimal displacement acuity, and Z is again the signal/noise ratio. The different dependences of spatial frequency resolution and of the reciprocal of the displacement sensitivity of a retinal ganglion cell model are shown in Figure 2, an unpublished figure from our work. The figure reveals that hyperacuity, the spread between the curves for spatial frequency resolution and reciprocal of displacement threshold, grows with increasing signal/noise ratio. The reason is that spatial frequency resolution is a saturating function of signal/noise while the reciprocal of the displacement resolution is proportional to signal/noise. This is evident from Figure 2.

We have also done calculations for other receptive field models: Gaussians, Difference of Gaussians, Gabor Functions, among others. In every case, the crucial parameter is signal/noise and the details of the shape of the spatial frequency response have only a small effect on the amount of hyperacuity. As a measure of hyperacuity we have taken the ratio of the reciprocal of the spatial frequency resolution to the displacement threshold. For a signal/noise of 15, this ratio ranges from 24 for a Gaussian to 31 for a Gabor function.

Neural Basis for Contrast Sensitivity.

We have determined that the major component in the computation of

brightnesses in a visual scene by the brain is the local retinal contrast, calculated in the retina prior to the retinal ganglion cells. Demonstrations of the importance of local retinal calculations are contained in the recent paper by Shapley (1986).

The primate retina is divided into groups of ganglion cells: the most numerous group of P cells that are wavelength selective and often color-opponent, and the less numerous M cells. M cells project to the lateral geniculate nucleus' Magnocellular layers, while the P cells send axons to the parvocellular layers. We have found that M cells have much higher contrast gain than P cells. This may mean that M cells have an important functional role in detecting luminance patterns and in providing good displacement acuity, and perhaps other hyperacuties. During the grant period we have written a research paper on the different contrast gains of P and M cells (Kaplan and Shapley, 1986) and I have collaborated on a review of P and M cell properties and their contribution to vision (Shapley and Perry, 1986).

Interpolated Contours: Possible Mechanisms

We have investigated the mechanisms for seeing interpolated borders in pictures like the Kanizsa triangle. These effects may seem to be curiosities at the periphery of visual perception, but I believe that the mechanisms for perceiving the subjective contours are probably the basis for most contour perception, and are therefore the basis for perception of form. As described in Shapley and Gordon (1985), we created circular objects around whose borders the contrast changed uniformly from positive to negative. Where the contrast went to zero there was no physical border, but a border was perceived by interpolation. What was most interesting about this phenomenon was that the border was interpolated between regions of opposite sign of contrast. This implied that the mechanism in the visual system that did the interpolation did not recognize the sign of the contrast, but rather responded to the magnitude of contrast independent of sign. This suggests a nonlinear, even-order border detecting mechanism, of the type described in Shapley and Gordon (1985) and (1986). We have also found that contrast and spatial separation influence the perception of interpolated borders in a manner consistent with the proposed nonlinear border-detecting mechanism.

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Figure Legends

Figure 1. Contrast sensitivity measured with rasters of variable frame rate. The subject adjusted the contrast of a sine grating until it was just invisible. The initial contrast was 0.1 The points are the average of five settings. The mean luminance was 100 cd/m². The filled circles are

for 30 Hz, while the empty circles are for 200 Hz.

Figure 2. Displacement acuity and spatial frequency resolution for a Gaussian receptive field. The solid line is the inverse of the spatial frequency resolution; the dashed curve describes the dependence of the displacement threshold on signal/noise ratio, the parameter Z . IN the graph Z is labeled DIMENSIONLESS GAIN because it can be considered to be the gain referred to the noise level. The separation between the dashed and solid curves is a measure of hyperacuity on a logarithmic scale.

Figure 1

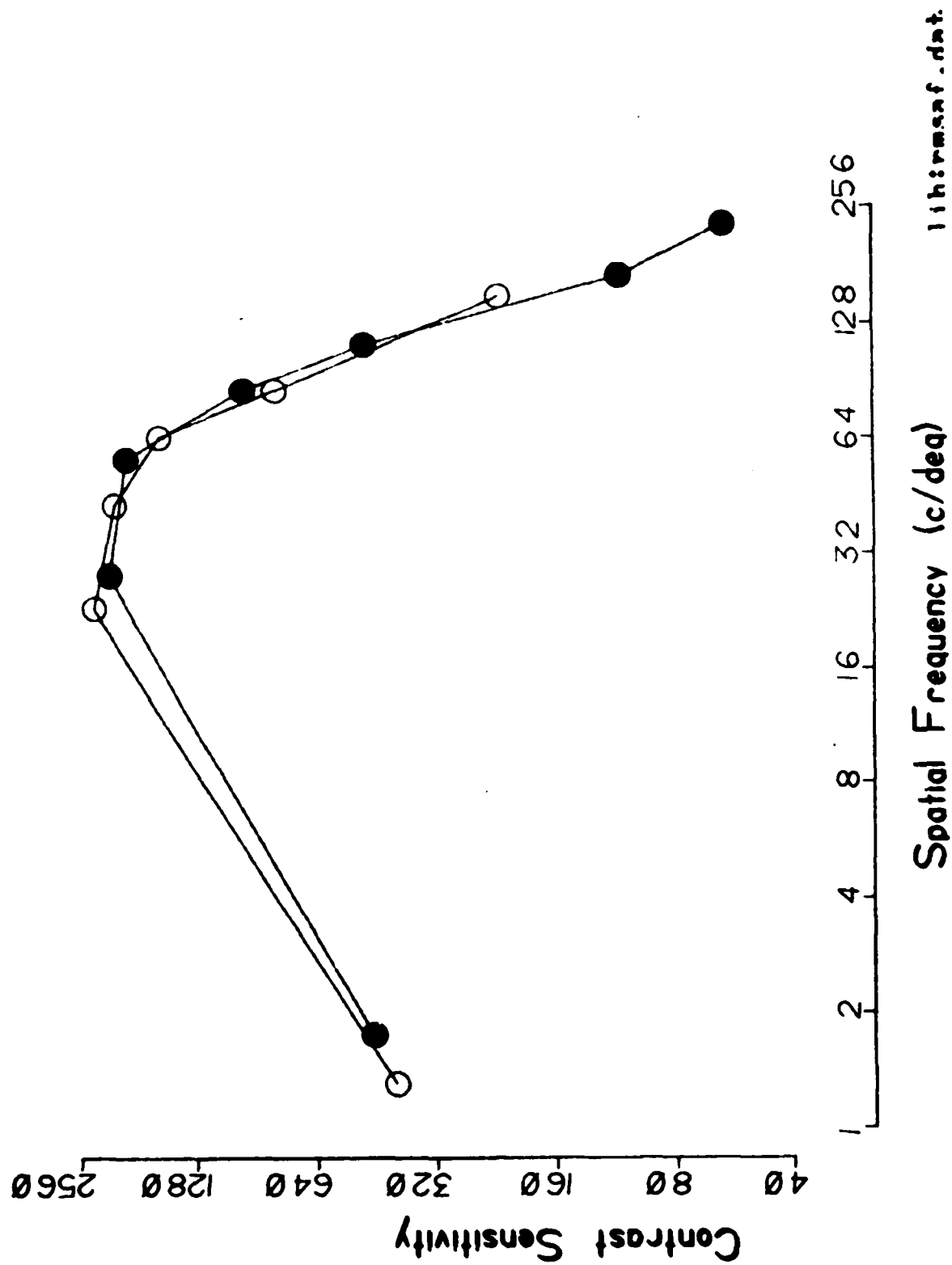
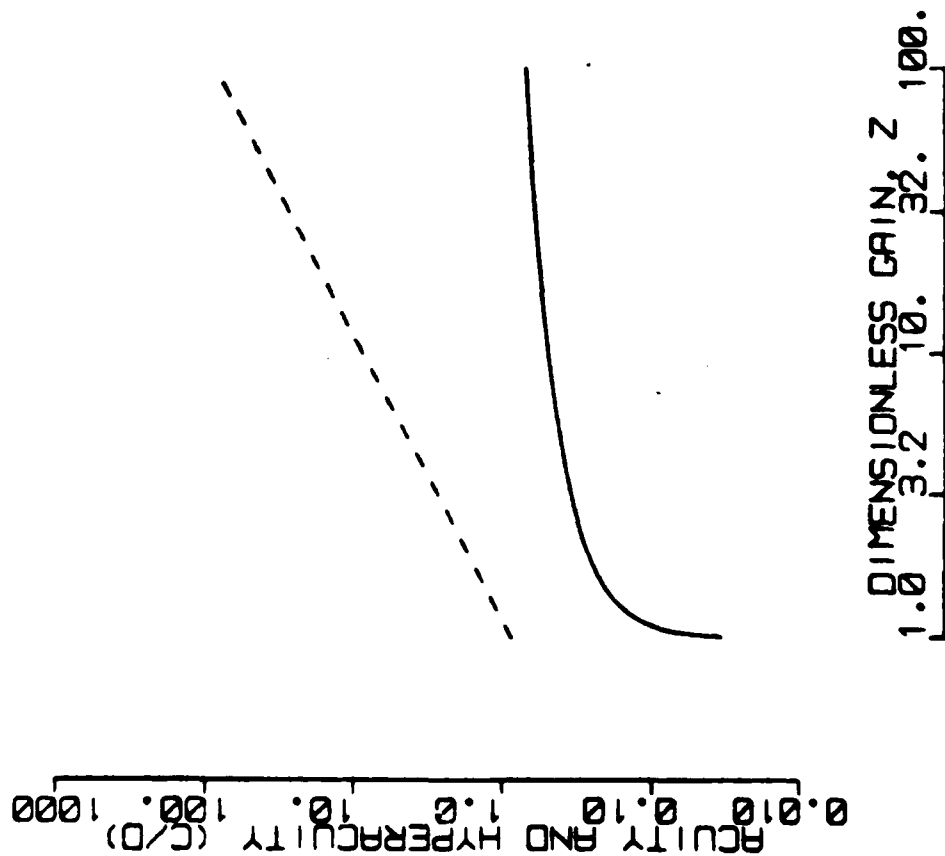


Figure 2

GAUSSIAN, $R = 1.000$ $K/KOPT = 1.000$



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